

# Exhibit 7



US007939967B2

(12) **United States Patent**  
**Humphrey et al.**

(10) **Patent No.:** **US 7,939,967 B2**

(45) **Date of Patent:** **May 10, 2011**

(54) **MULTIPLE POWER SUPPLY CONTROL**

(56) **References Cited**

(75) Inventors: **Daniel Humphrey**, Houston, TX (US);  
**Amin Bemat**, Cypress, TX (US);  
**Reynaldo Domingo**, Spring, TX (US)

(73) Assignee: **Hewlett-Packard Development Company, L.P.**, Houston, TX (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 208 days.

#### U.S. PATENT DOCUMENTS

4,860,188 A	8/1989	Bailey	
5,200,643 A	4/1993	Brown	
5,675,480 A	10/1997	Sanford	
5,894,413 A *	4/1999	Ferguson	363/65
7,082,042 B2	7/2006	Harris	
7,368,832 B2	5/2008	Peck	
7,436,950 B2	10/2008	Chheda	
7,701,089 B2 *	4/2010	Shimizu	307/80
2008/0191552 A1	8/2008	Suzuki	
2009/0224603 A1 *	9/2009	Perper et al.	307/43

\* cited by examiner

*Primary Examiner* — Robert L. Deberadinis

(21) Appl. No.: **12/491,773**

(22) Filed: **Jun. 25, 2009**

(65) **Prior Publication Data**

US 2010/0327656 A1 Dec. 30, 2010

(51) **Int. Cl.**  
**H02J 9/00** (2006.01)

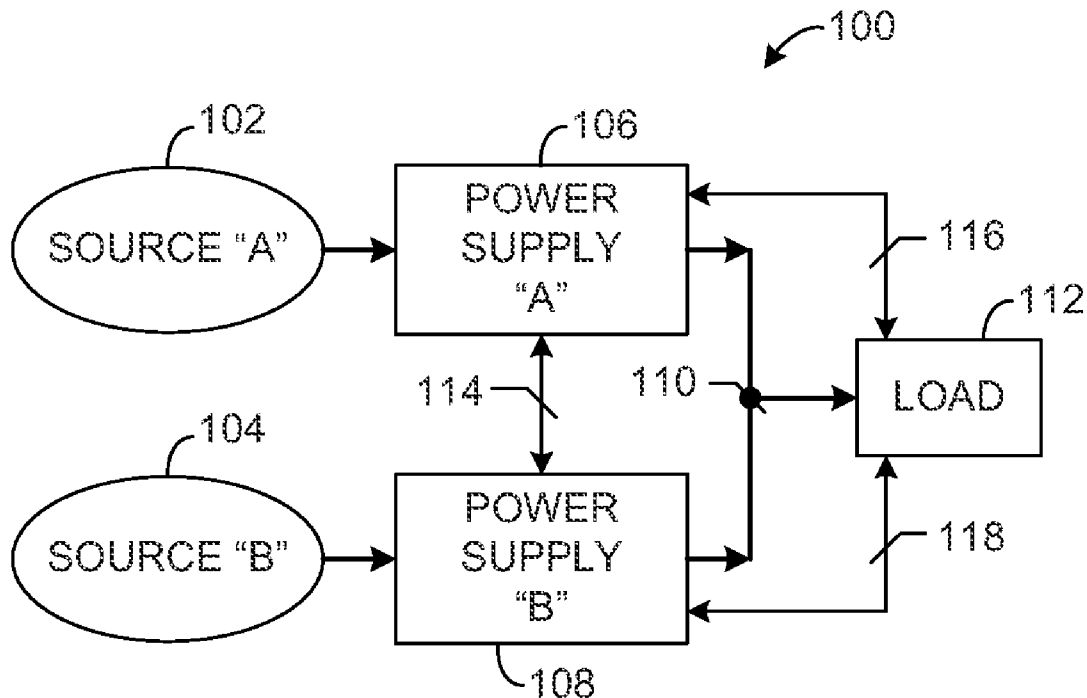
(52) **U.S. Cl.** ..... 307/65

(58) **Field of Classification Search** ..... 307/65  
See application file for complete search history.

#### ABSTRACT

Apparatus and methods are provided. A system includes two or more power supplies receiving electrical energy from respective independent sources. One of the power supplies detects an anomalous condition of the associated energy source and provides an alert signal. At least one of the other power supplies transitions from a standby mode to a normal output mode in response to the alert signal. The failing power supply provides operating level energy to an electrical load while the one or more other power supplies transition from standby to normal output level.

**15 Claims, 3 Drawing Sheets**



U.S. Patent

May 10, 2011

Sheet 1 of 3

US 7,939,967 B2

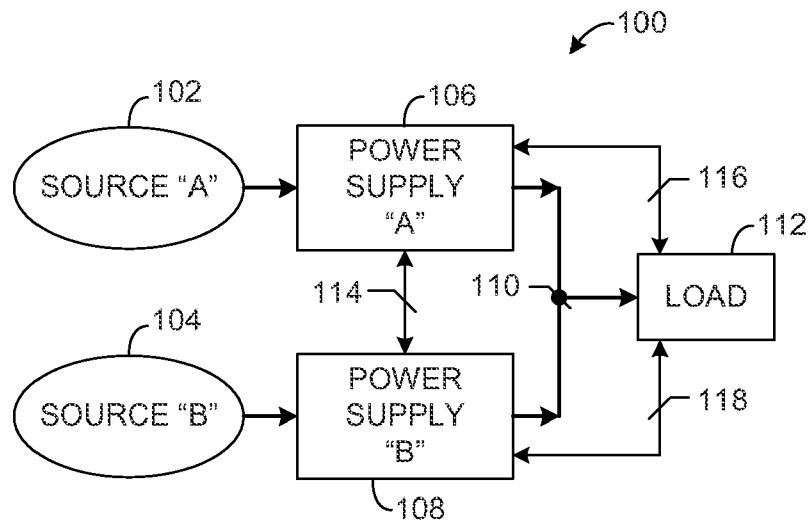


FIG. 1

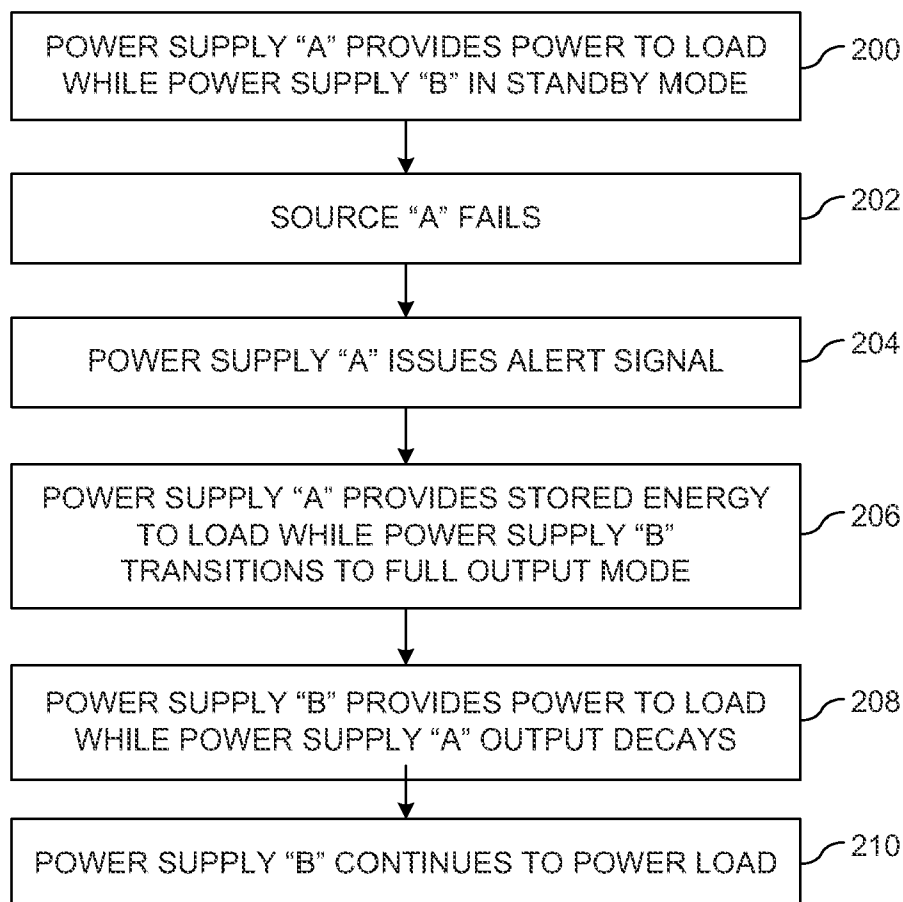


FIG. 2

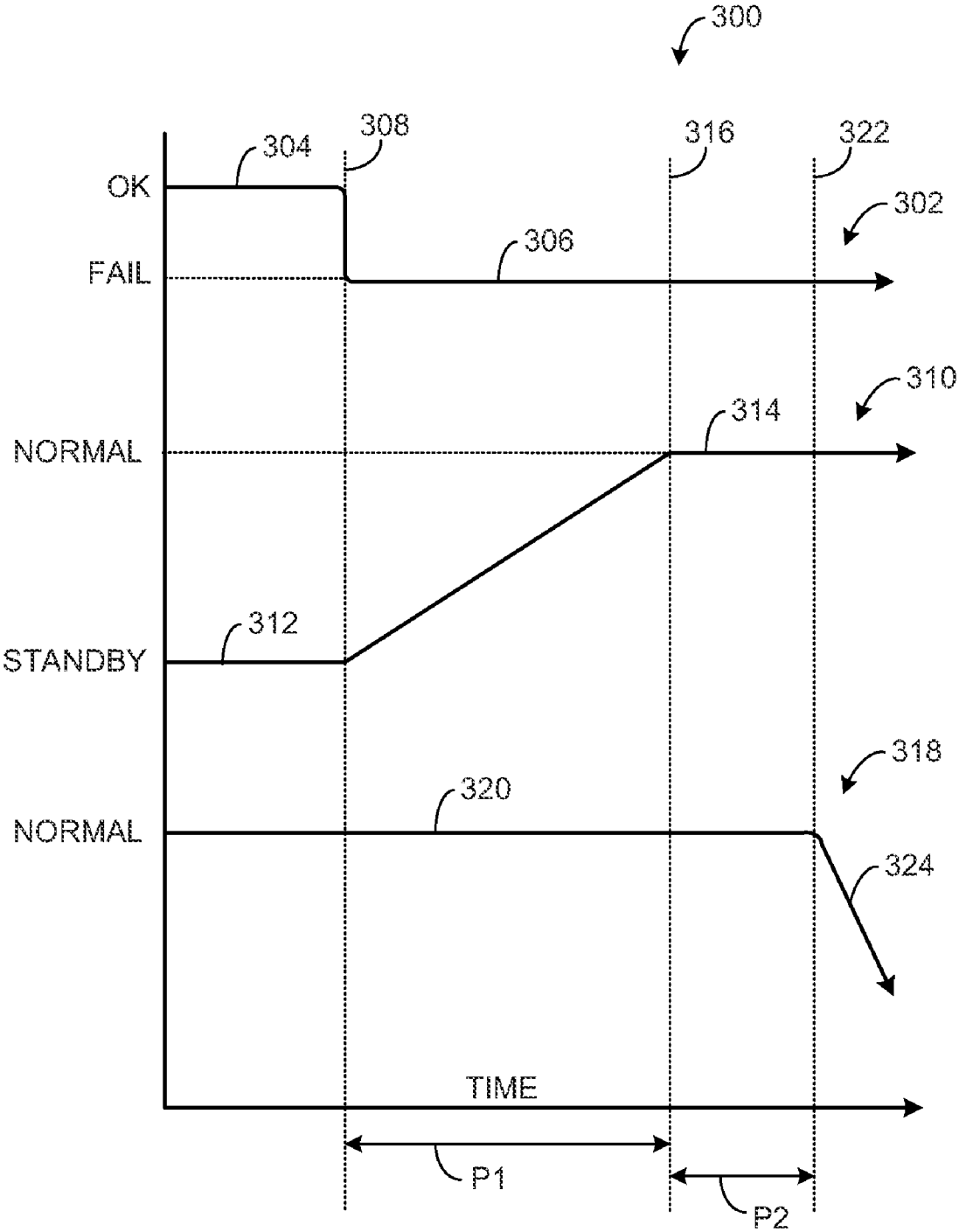


FIG. 3

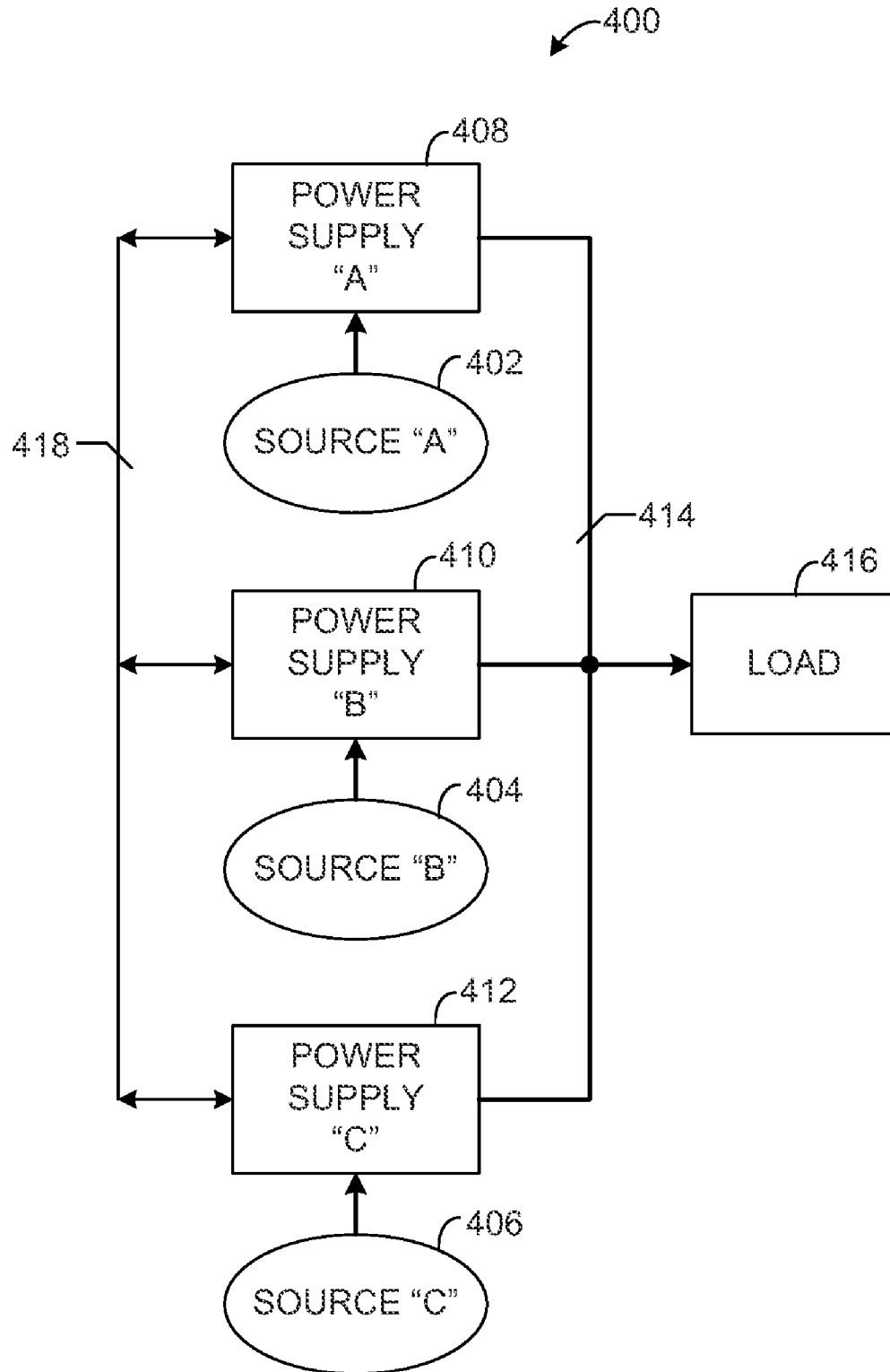


FIG. 4

## US 7,939,967 B2

1

## MULTIPLE POWER SUPPLY CONTROL

## BACKGROUND

Various devices and systems use multiple power supplies in order to increase reliability or “up time” through redundancy. In a typical scenario, each operating power supply bears an approximately equal share of the load. However, such a balanced load sharing approach often results in each power supply operating with less than optimum efficiency. The present teachings address the foregoing and other concerns.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present embodiments will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 depicts a block diagram of a system according to one embodiment;

FIG. 2 depicts a flow diagram of a method according to one embodiment;

FIG. 3 depicts a signal timing diagram according to an embodiment;

FIG. 4 depicts a block diagram of a system according to another embodiment.

## DETAILED DESCRIPTION

## Introduction

Means and methods for providing redundant power supplies are described. An illustrative system includes two or more power supplies each coupled to electrical energy at respective independent source. One of the power supplies detects an anomalous condition in the associated energy source and provides an alert signal. At least one of the other power supplies transitions from a standby mode to a normal output mode in response to the alert signal. The failing power supply provides operating level energy to an electrical load while the one or more respondent power supplies transition from standby to normal output levels.

In one embodiment, an apparatus includes a first power supply coupled to an electrical load and a first source of electrical energy. The first power supply is configured to issue an alert signal indicative of a failure condition of the first source of electrical energy. The apparatus also includes a second power supply coupled to the electrical load and a second source of electrical energy. The second power supply is configured to transition from a lesser output level to a greater output level in response to an activation signal.

In another embodiment, a system includes an electrical load and a first power supply. The first power supply is coupled to a first independent source of electricity and to the electrical load. The first power supply is configured to provide a first alert signal indicative of an anomalous condition of the first independent source of electricity. The system also includes a second power supply coupled to a second independent source of electricity and to the electrical load. The second power supply is configured to provide a second alert signal indicative of an anomalous condition of the second independent source of electricity. The first power supply is further configured to transition from a lesser output level to a greater output level in response to a first activation signal. The second power supply is further configured to transition from a lesser output level to a greater output level in response to a second activation signal.

2

In yet another embodiment, a method includes asserting a signal responsive to an anomalous condition of a first independent source of electrical energy. The first independent source of electrical energy is coupled to energize a first power supply. The method also includes transitioning a second power supply from a standby output level to a normal output level responsive to the signal. The second power supply is energized by a second independent source of electrical energy. The method further includes providing operating power from the first power supply to an electrical load during the transitioning.

## First Illustrative Embodiment

Reference is now directed to FIG. 1, which depicts a block diagrammatic view of a system 100. The system 100 is illustrative and non-limiting with respect to the present teachings. Thus, other systems can be configured and operated in accordance with the present teachings.

The system 100 includes two independent sources of electrical energy (sources) 102 and 104, respectively. The source 102 is also designated source “A”, while the source 104 is designated source “B” for purposes of simplicity. Each source 102 and 104 is autonomous and operates without dependence or interaction with the other. For purpose of non-limiting example, each of the sources 102 and 104 can be defined by a respective power distribution utility, a generator set, an inverter powered by solar or wind energy, etc. Other configurations or definitions of the independent energy sources 102 and 104 are also possible. A failure of one of the sources 102 and 104 is presumed, in and of itself, to have no affect on the other. Thus, the sources 102 and 104 are redundant with respect to the balance of the system 100.

The system 100 also includes a first power supply 106, also designated as power supply “A”. The system 100 further includes a second power supply 108, also designated as power supply “B”. The power supplies 106 and 108 are energized by the sources 102 and 104, respectively. Each of the power supplies is coupled to provide conditioned power 110 to a load 112. Thus, each power supply “A” and “B” (106 and 108) is configured to perform voltage regulation, current limiting, or other operations.

Each power supply 106 and 108 is configured to provide for at least a portion of the electrical needs of the load 112. In one embodiment, each of the power supplies 106 and 108 is capable of providing all operating power 110 to the load 112, such that complete redundancy is provided within the system 100.

Additionally, the power supplies 106 and 108 can be respectively configured and coupled to one another so as to bidirectionally exchange signals 114. Such signals 114 can include status information, alerts and other signals as various events occur making such communications relevant. In the alternative, power supply 106 can be coupled to the load 112 so as to communicate signals 116, while power supply 108 can be coupled to the load 112 so as to communicate signals 118. In this alternative way, each power supply 106 and 108 can communicate respective signals 116 and 118 to the load 112. In turn, the load 112 is configured to respond by relaying the same signal or another corresponding signal to the other power supply 106 or 108.

Power supplies 106 and 108 can respectively include any circuitry, processor(s) or other resources as needed in order to perform in accordance with the present teachings. Such resources can include, for purposes of non-limiting illustration, one or more state machines, digital logic, analog circuitry, digital/analog hybrid circuitry, one or more processors

## US 7,939,967 B2

3

or microcontrollers, lookup tables, voltage or current sensing elements, etc. One having ordinary skill in the electrical and related arts will appreciate that sensing and signaling instrumentation is well known, and that further particular elaboration is not required for an understanding of the present teachings.

Illustrative operation of the system **100** is described below with respect to FIG. **2**.

#### First Illustrative Method

FIG. **2** is a flow diagram depicting a method according to one embodiment of the invention. The method of FIG. **2** includes particular operations and order of execution. However, other methods including other operations, omitting one or more of the depicted operations, and/or proceeding in other orders of execution can also be used according to the present teachings. Thus, the method of FIG. **2** is illustrative and non-limiting in nature.

At **200**, a first power supply provides all needed operating power to a load, while a second power supply operates in a standby mode. For purpose of illustrative example, it is assumed that the power supply “A” **106** provides all needed conditioned power **110** to a load **112**. It is also assumed that the power supply “B” **108** operates in a standby mode, providing no power output to the load **112**.

At **202**, a first independent source of energy fails. For purposes of the ongoing example, it is assumed that independent source “A” **102** fails in a low-voltage or no-voltage condition. Other anomalous conditions of the source **102** can also occur.

At **204**, the first power supply detects the anomalous (failed) condition of the first independent energy source and issues a corresponding input fault signal. For purposes of example, it is assumed that power supply “A” **106** detects the failed condition of source **102** and issues an input fault signal **114** to power supply “B” **108**. The input fault signal can also be referred to as an alert signal **114**.

At **206**, the first power supply continues to provide energy from storage to the load while the second power supply transitions to a full (i.e., normal) output mode. For purposes of the example, it is assumed that the power supply **106** includes capacitors or other internal storage (not shown) sufficient to provide conditioned power **110** to the load **112**, while the power supply **108** transitions from standby (i.e., no output) to full power output mode. One of ordinary skill in the electrical arts will appreciate that the use of output filtering, buffering or energy storage capacitors within power supplies is a common practice, and no additional elaboration is required in this regard.

At **208**, the second power supply provides full, normal operating power to the load while the first power supply output decays. For purposes of the example, it is assumed that the power supply “B” **108** is now operating at full output, sufficient to provide all needed power to the load **112**. Additionally, the power supply “A” **106** output is presumed to decay below useful levels as the internal storage capacitors are discharged.

At **210**, the second power supply continues to provide for the needs of the load despite the failed or anomalous condition of the first independent energy source. For purposes of the example, power supply “B” **108** powers the load **112**, by virtue of the second independent energy source **104**.

The method described is just one of any number of methods contemplated by the present teachings. In general, anticipated failure of a power supply results in the provision of a corresponding alert (or activation) signal or message. Another power supply, operating in a no-output (i.e., standby) mode responds to the signal by transitioning as quickly as possible

4

to a full output operating mode. The soon-to-fail power supply can provide a brief period of normal operating power to a load or loads, by virtue of internal or external energy storage, while the other power supply is in transition.

In this way, a brief period occurs during which the two power supplies are providing respective fractions of the required load power. The responding or “take over” power supply assumes full duty prior to and during the decay and failure of the other power supply. The method allows for each of the power supplies to operate at or near optimum efficiency while providing for the electrical demands of the load being served.

Additionally, the system **100** can, but not necessarily, be further configured such that the power supply “A” **106** is designated as a primary supply, while the power supply “B” **108** is designated as a backup supply. In such a further configuration, restoration of the first independent source of energy **102** results in the power supply “A” **106** issuing a standby signal to the power supply “B” **108**. In response, the power supply “B” **108** transitions from full output mode to the standby mode, while the power supply “A” **106** assumes full output operation and provides for the needs of the load **112**. It is noted that the “A” and “B” designations of system **100** are arbitrary, and do not necessarily correspond to a hierarchical operating scheme.

The present teachings contemplate various systems in which multiple power supplies of essentially identical output and signaling capabilities are used to provide for redundancy within the respective systems. The method of FIG. **2** is performed in the context of a two source/two power supply system (e.g., system **100**). However, the present teachings contemplate substantially equivalent methods that are performed in the context of respective systems having any practical number of independent energy sources and power supplies.

For non-limiting example, a system (not shown) can be provided having a total of four power supplies energized by a total of two independent electrical sources. The power supplies of such a system can be arranged as cooperative pairs coupled to the two respective sources. Thus, the failure of one independent source leaves two power supplies still operational by virtue of the other independent source. Alternatively, two power supplies, each coupled to a respective source, can operate in the interest of load balancing. In this alternative, two standby power supplies are present and coupled to the respective sources. Such a four power supply, two independent source configuration is referred to as a “2+2” scheme. Other redundancy schemes (i.e., N+N) are also contemplated by the present teachings, wherein communication signaling between respective power supplies allows for primary/standby operation at or near optimum efficiency.

#### Illustrative Signal Diagram

FIG. **3** is a signal timing diagram **300** according to one illustrative and non-limiting embodiment. The diagram **300** is provided for purposes of clarity.

The diagram **300** includes a voltage **302** corresponding to a particular independent source of electrical energy. As depicted, the voltage **302** drops from a normal (“OK”) operating level **304** to an insufficient (“FAIL”) level **306** at a time **308**.

The diagram **300** also includes an output voltage **310** provided by a “standby” power supply “B” of an illustrative redundant system. The voltage **310** is initially at a standby (zero) output level **312**. Then, the voltage **310** begins to transition toward a full operating level **314** starting at time **308**. It is assumed that the transition from standby level **312** toward full output level **314** is triggered by an alert, activation or

## US 7,939,967 B2

5

other signal provided to power supply “B”. The transition of the voltage **310** occurs during a time period P1 from time **308** to a time **316**.

The timing diagram **300** further includes an output voltage **318** provided by a “primary” power supply “A” of the illustrative redundant system. It is assumed that the power supply “A” is energized by the independent source of voltage **302**. As such, the power supply “A” is deprived of normal input electrical energy beginning at time **308** and thereafter as depicted in FIG. 3.

The voltage **318** is initially at full output (normal operating) level **320**. This normal (i.e., regulated) output level **320** continues until time **322**, at which point the voltage **318** assumes a rate of decay **324** as the energy storage (not shown) is discharged below controllable output levels. However, it is noted that there is an overlap period P2 between times **316** and **322** in which voltages **310** and **318** are both at full output level. As a result, the load served by voltages **310** and **318** is not subject to an interruption in operating power, despite the failure of independent voltage **302**.

## Second Illustrative Embodiment

Reference is now directed to FIG. 4, which depicts a block diagrammatic view of a system **400** in accordance with another embodiment. The system **400** is illustrative and non-limiting with respect to the present teachings. Thus, other systems can be configured and/or operated in accordance with the present teachings.

The system **400** includes three independent sources of electrical energy **402**, **404** and **406** (inclusive). The sources **402-406** are coupled to provide electrical energy to three power supplies **408**, **410** and **412**, respectively. In turn, the power supplies **408-412** are each configured to provide some or all of the electrical energy **414** required by a load **416**.

The power supplies **408-412** are further respectively configured to communicate signals **418** pertaining to individual operating status, status of the respective independent energy sources **402-406**, etc. In this way, the power supplies **408-412** can operate in respective standby and full (normal) output modes, and provide signals **418** to one another when a failure is imminent.

For non-limiting example, power supply “A” **408** can provide for the full energy needs of the load **416**, while power supply “B” **410** and power supply “C” **412** operate in standby mode. If power supply “A” **408** detects a failure—that is, any predefined and detectable anomaly—of the energy source **402**, then power supply “A” **408** can provide a signal **418** requesting power supply “B” **410** to assume full output operating status. In the event that power supply “B” **410** cannot or does not respond, power supply “A” **408** can provide a signal **418** requesting power supply “C” **412** to assume full operating status. Power supply “A” **408** can provide a brief period of full output power while the responding power supply “B” **410** or “C” **412** completes the transition period from standby to normal (i.e., full) output.

In another non-limiting example, power supplies “A” **408** and “B” **410** provide for respective (e.g., balanced, or fifty percent) portions of the electrical energy **414** required by the load **416**, while power supply “C” **412** operates in standby mode. In the event that power supply “B” **410** detects an anomalous condition of the independent power source **404**, power supply “B” **410** can provide a signal **418** requesting that power supply “C” **412** assume normal operating mode. The power supply “B” **410** can continue to provide a brief period of normal (full) output, by virtue of energy storage,

6

while power supply “C” **412** completes the transition period from standby to full output mode.

In general, the foregoing description is intended to be illustrative and not restrictive. Many embodiments and applications other than the examples provided would be apparent to those of skill in the art upon reading the above description. The scope of the invention should be determined, not with reference to the above description, but should instead be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. It is anticipated and intended that future developments will occur in the arts discussed herein, and that the disclosed systems and methods will be incorporated into such future embodiments. In sum, it should be understood that the invention is capable of modification and variation and is limited only by the following claims.

What is claimed is:

1. An apparatus, comprising:

a first power supply coupled to an electrical load and a first source of electrical energy, the first power supply configured to issue an alert signal indicative of a failure condition of the first source of electrical energy; and a second power supply coupled to the electrical load and a second source of electrical energy, the second power supply configured to transition from a lesser output level to a greater output level in response to an activation signal.

2. The apparatus according to claim 1, the first power supply further configured to provide operating power to the electrical load while the second power supply transitions from the lesser output level to the greater output level.

3. The apparatus according to claim 1, the first and second power supplies being coupled such that the activation signal is defined by the alert signal.

4. The apparatus according to claim 1, the electrical load being configured to provide the activation signal to the second power supply in response to the alert signal from the first power supply.

5. The apparatus according to claim 1, the first power supply further configured to transition from a lesser output level to a greater output level in response to a signal indicative of an anomaly in the second source of electrical energy.

6. The apparatus according to claim 1, at least the first or second power supply configured to operate at a lesser output level in response to a standby signal, the first power supply further configured to transition from the lesser output level to a greater output level in response to a respective activation signal.

7. The apparatus according to claim 1 further comprising a third power supply configured to transition from a lesser output level to a greater output level in response to an activation signal.

8. The apparatus according to claim 1, the first power supply further configured to provide operating level power from internal energy storage to an electrical load while the second power supply transitions from the lesser output level to the greater output level in response to the activation signal.

9. A system, comprising:

an electrical load;

a first power supply coupled to a first independent source of electricity and to the electrical load, the first power supply configured to provide a first alert signal indicative of an anomalous condition of the first independent source of electricity; and

a second power supply coupled to a second independent source of electricity and to the electrical load, the second power supply configured to provide a second alert signal

US 7,939,967 B2

7

indicative of an anomalous condition of the second independent source of electricity, the first power supply further configured to transition from a lesser output level to a greater output level in response to a first activation signal, the second power supply further configured to transition from a lesser output level to a greater output level in response to a second activation signal.

10. The system according to claim 9, at least the first or second power supply further configured to operate at a lesser output level in response to a standby signal.

11. The system according to claim 9, the first and second power supplies respectively configured to provide operating level power to the electrical load for an amount of time sufficient for the other of the first and second power supplies to transition from the lesser output level to the greater output level.

12. The system according to claim 9, the second activation signal defined by the first alert signal, the first activation signal defined by the second alert signal.

13. The system according to claim 9, the electrical load configured to provide the second activation signal in response

8

to the first alert signal, the electrical load further configured to provide the first activation signal in response to the second alert signal.

14. A method, comprising:  
asserting a signal responsive to an anomalous condition of a first independent source of electrical energy, the first independent source of electrical energy coupled to energize a first power supply;  
transitioning a second power supply from a standby output level to a normal output level responsive to the signal, the second power supply energized by a second independent source of electrical energy; and  
providing operating power from the first power supply to an electrical load during the transitioning.

15. The method according to claim 14 further comprising communicating the signal from the first power supply to the second power supply, the second power supply providing operating power to the electrical load after the transitioning to normal output level.

\* \* \* \* \*